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Multiplex Combinations for
Economic Telegraphy & Telephony

Electrical Engineering

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MULTIPLEX COMBINATIONS
FOR ECONOMIC TELEGRAPHY
AND TELEPHONY

BY

RUPERT FORREST JONES

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Rupert Forrest Jones

ENTITLED Multiplex Combinations for Economic Telegraphy
and Telephony.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

Morgan Brooks

Instructor in Charge

APPROVED:

Ernst Berg

HEAD OF DEPARTMENT OF Electrical Engineering



Multiplex Combinations for Economic Telegraphy and Telephony.

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MULTIPLEX COMBINATIONS FOR ECONOMIC TELEGRAPHY AND TELEPHONY.

I.

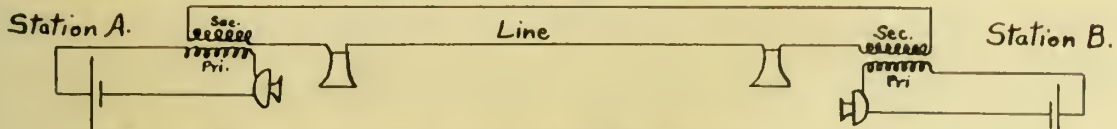
Introduction.

Before the invention of the telephone, duplex and quadruplex telegraphy had been introduced, by which two or four messages could be transmitted telegraphically without interference. Although these inventions require that half the messages shall be in each direction over the wire, the economy of line construction and maintenance is self-evident. The invention of the telephone came as a direct result of the efforts of two men, Elisha Gray and Alexander Graham Bell, to solve the problem of multiplex harmonic telegraphy, involving the use of several vibrating reeds or forks actuated electrically over a single line, each pitch carrying one message. Naturally, the duplexing and multiplexing of telephone circuits was studied early in the art. The telegraphic schemes were not found applicable immediately to telephony, but a scheme of simultaneous telegraphy and telephony was early tried, although no great commercial use of the various ideas proposed was made until within the last ten years or so. Adequate descriptions of the various methods in use in this country are not readily available, and therefore it was taken as a suitable subject for a thesis.

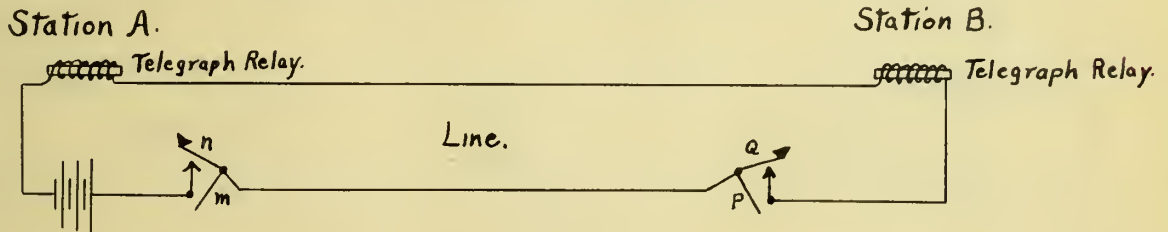
In telegraphic service it is possible to consider transmitting only a part of the electrical current, if the remainder is sufficient to actuate a delicate relay, and this idea is fundamental in some multiplex telegraph schemes. In telephony, especially for long lines, it is important that no loss of current or of electromotive force be suffered, as the receiving instruments need all of the small power that is available. Therefore, the combinations of circuits in use are not based, as might be expected, upon well known telegraph schemes.

Simultaneous telegraphy and telephony over a single circuit is known as a Simplex System. Two telephone messages transmitted over one circuit is Duplex Telephony. In general, if two or more telephonic messages are transmitted without interference over a less number of circuits than the number of messages, the system is known as Multiplex Telephony. The most common instance of this is where two telephone circuits are utilized for a third telephone message over the two original circuits in parallel, the third being known as a Phantom Circuit. When there is such a phantom, it is customary to denote one of the fundamental circuits as a Physical Circuit, a term quite unnecessary where multiplexing is not in use. A combination of circuits that will allow the transmission of one telephone and two telegraph messages at the same time over one pair of line wires is termed a Composite System. This term is also given a similar arrangement of apparatus that will permit the transmission of one telephone and one telegraph message at the same time over a single line wire. In the latter arrangement, the ground is the common return for both telephone and telegraph currents.

Possibility of Combining a Telegraph and Telephone Circuit.



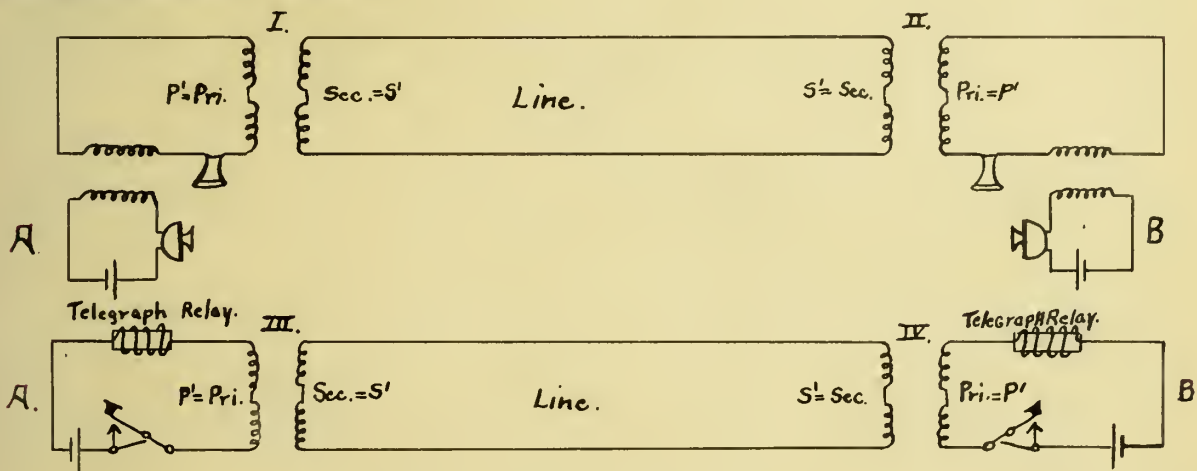
When fluctuating current is caused to flow in the primary circuit at station "A" in the above circuit, due to the pressure variation on the transmitter diaphragm by the voice, there are alternating currents induced in the secondary which are received by the receiver at station "B". The receiver magnet will be energized by an amount proportional to the instantaneous values of the wave of current flowing for each impulse of the voice. The telephone line is therefore a transmission line capable of carrying alternating current.



When the switch "M" is closed at Station "A" in the above circuit and messages are sent to Station "A" from "B" by alternately closing and opening "Q", a pulsating current is sent over the line and the relay at "A" is correspondingly energized and de-energized. This line is therefore carrying a pulsating direct current, but no alternating current.

Since the telephone and telegraph lines are carrying currents which are vibratory in value, they are thus capable of producing inductive "e.m.f.s" in helical coils, which might be connected in series in the respective lines. Of course,

neither one of the lines would work if a helical or so called choke coil were connected in the line, since the "e.m.f." of self-induction would choke back the pulsation which is to be received on the opposite end of the line. However, this inductance property can be taken advantage of in combining the lines. Suppose an induction coil consisting of two coils of an equal number of turns were connected in the respective lines as shown below.



For the telephone line, the same voltage is induced in S' as is impressed on P' since the windings have an equal number of turns. Hence, it would seem that the voice would be transmitted with the same volume from one end to the other of the line as for the condition without the induction coils.

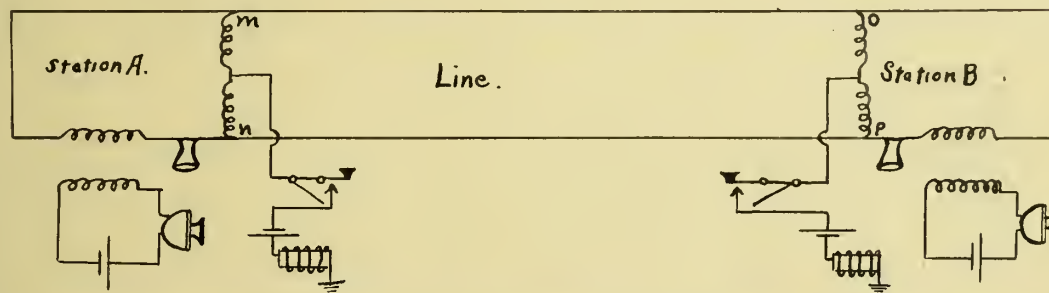
As for the telegraph circuit, it would not work since alternating current flows from the secondary on the sending end of the line, which is also impressed on the secondary end, an alternating current also being induced in the corresponding primary. The relay would thus not respond to the correct time interval for dots and dashes from the sender, there being

nothing but dots received, and a dot for each make and each break of the key. Also, the man receiving would be powerless to break the circuit at his key to ask for a repetition of a word or sentence.

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-III-
Systems of Combination.

From the previous discussion it is seen that the telephone and telegraph line combination must thus be so made that the telegraph line will work metallic.

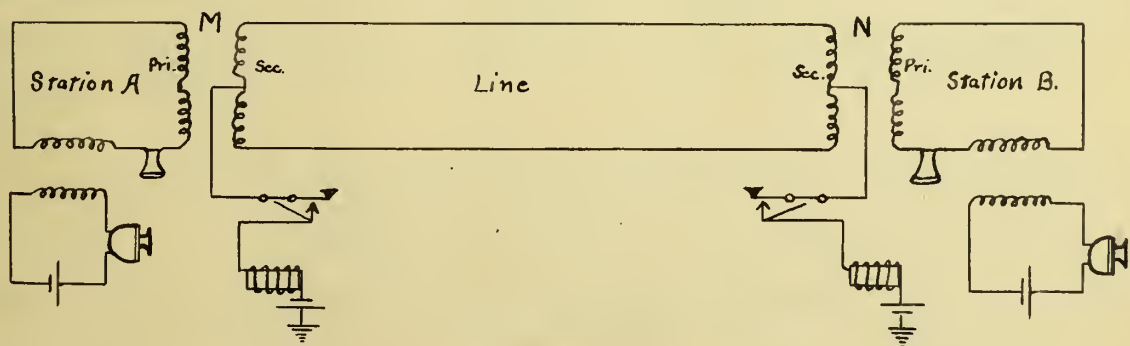
The Simplex System is one of the most representative methods. There are two types of Simplex Systems, namely, the "Impedance Coil" and "Repeating Coil". The so called "Impedance Coil Simplex" is shown in diagram below.



The coils (m) and (n) at Station "A" are two impedance coils in series, and with an equal number of turns. The resistance of these coils used by the Bell Telephone Company are each 500 ohms. The coils "o" and "p" at Station "B" are of the same type. It is seen that the two telephone instruments work over the two wires, as would be expected. When the telegraph key is closed at Station "A", the current is sent over the wire connected to the middle of the two impedance coils and out on to the line wires to be received by the relay at Station "B". Neither telephone receiver will receive any telegraph current since half of the current flows through coil "m" and half through "n". The potentials at the outer ends of the coils are of the same sign, and are equal, since the in-

ductance is the same in both coils. If the drop in each line wire is the same, the received potentials counteract each other in the receiver at Station "B" and no current flows in the receiver. The current must get back to the battery and has a ready path through coils "O" and "P" from each line wire, and passes through the closed instrument at Station "B" to the battery; the groups of cells at "A" and "B" respectively being in series through the ground. The inductances of the coils "O" and "P" are equal, as is the case for "M" and "N". An induced leakage telephone current cannot flow through the telegraph instruments since there is no connection from the ground to the lines, if the latter are in the clear on the poles.

The impedance coils however, form a high resistance short circuit to the telephone, and ringing currents, this being eliminated by the Repeating Coil System. The underlying theory for the Repeating Coil Simplex is the same as for the Impedance Coil Simplex, there being a few variations in the construction.



Transformers with windings of an equal number of turns are represented in circuit at "M" and "N" respectively. The resistance of the primary (instrument side) of each transformer is nearly equal to that of the secondary (line side), and the inductances are equal. The transformers "M" and "N" are

called "Repeating Coils.

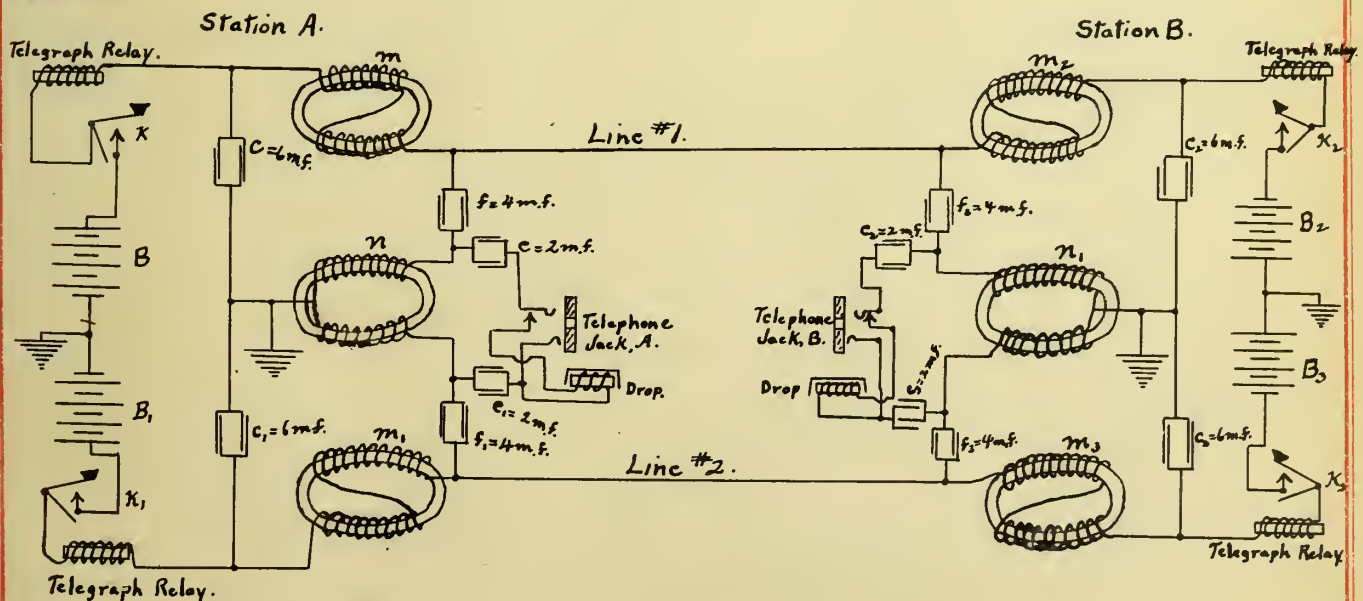
When a person speaks into the transmitter at Station "A", the fluctuating voice current, impressed on the primary of Coil "M", induces an equal frequency current in the secondary which is transmitted over the line and is received in the secondary of coil "N". This current again induces one of the same frequency in the primary, which flows through the receiver at Station "B". The sound of the voice is thus maintained.

A telegraph current sent from station "A" passes through the two halves of the secondary of coil "M", passes over the two line wires in parallel and through the two halves of the secondary of Coil "N" and thence through the telegraph relay at "N" and back to the battery. The inducing action of this current is neutralized in the secondary, as the tap is made to the telegraph instrument at the center of the secondary winding. Thus, no telegraph impulse is heard in the receiver at stations "A" and "B". If the line is clear of a ground, none of the induced telephone current will leak through the telegraph instruments.

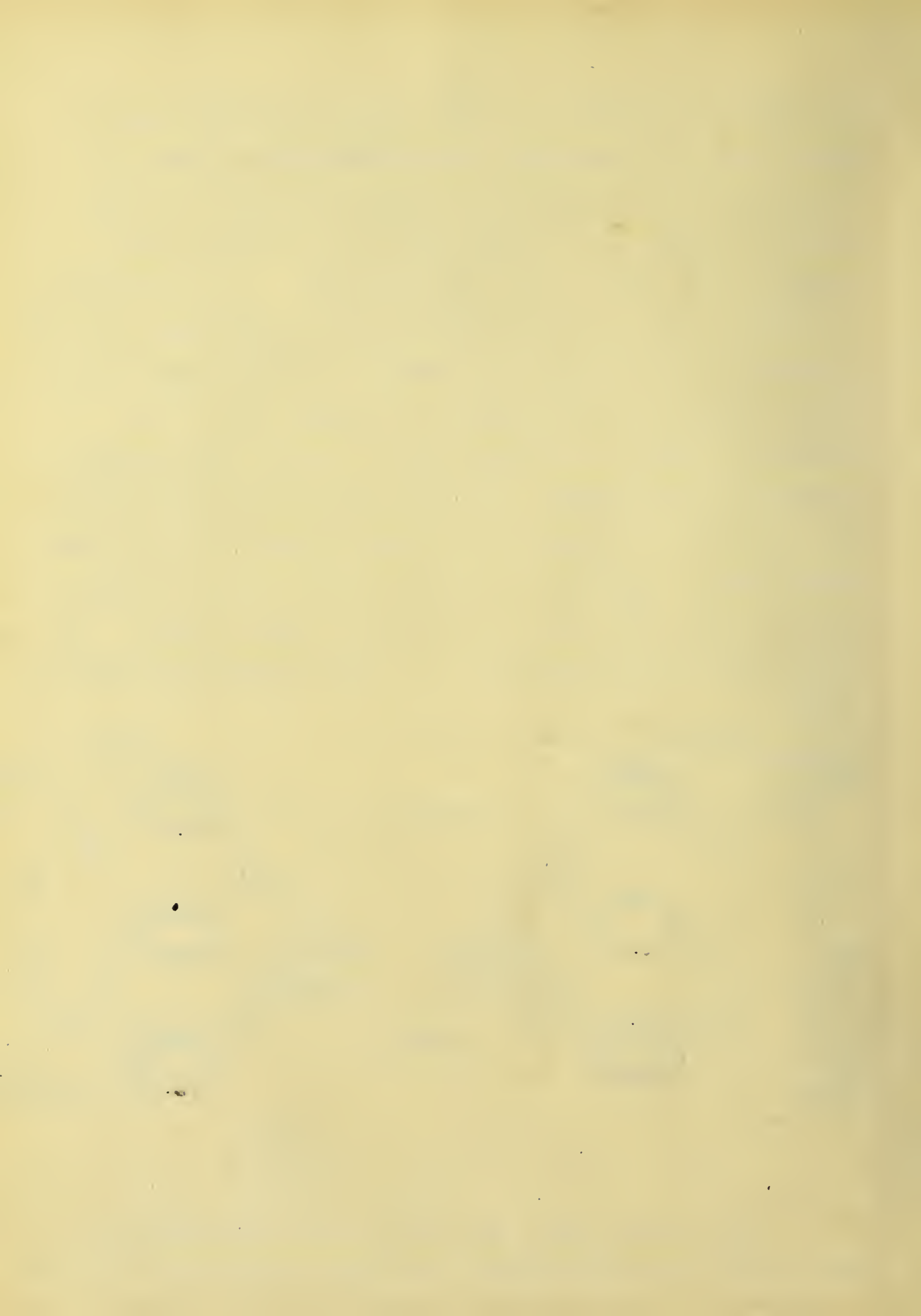
This system as used by the American Telephone and Telegraph Company has proved to be superior to the Impedance Coil method, and it has the advantage that the regular cord circuits and ringing machines may be used in connecting together two such circuits, without affecting the telegraph apparatus adversely.

A "Composite System" gives a very efficient and economical means of transmitting telephone and telegraph messages. The modern Bell testboards are so constructed that a Simplex System can readily be made into a Composite System. In case

of unexpected crosses or grounds in any of the Bell long distance lines it is essential that some means be provided to quickly put the telephone and telegraph instruments working between stations, as it means a great loss of money to the Company to have any of their lines disabled. It is not always possible to send a repairman immediately over the line, or it may take him some time to find the trouble. The telegraph circuits suffer principally from these line troubles, and if it is possible to form up a composite between cities, two telegraph circuits can be completed around to terminating points over one pair of wires in addition to a telephone circuit, and this means great saving. The Simplex Systems are cut over into Composite Systems at the test board by the means of plugs in jacks. The general make up and description of a Composite will be presently given.



Wires marked Line 1 and Line 2, may be considered as a pair on pole cross arms between two cities marked Station "A" and



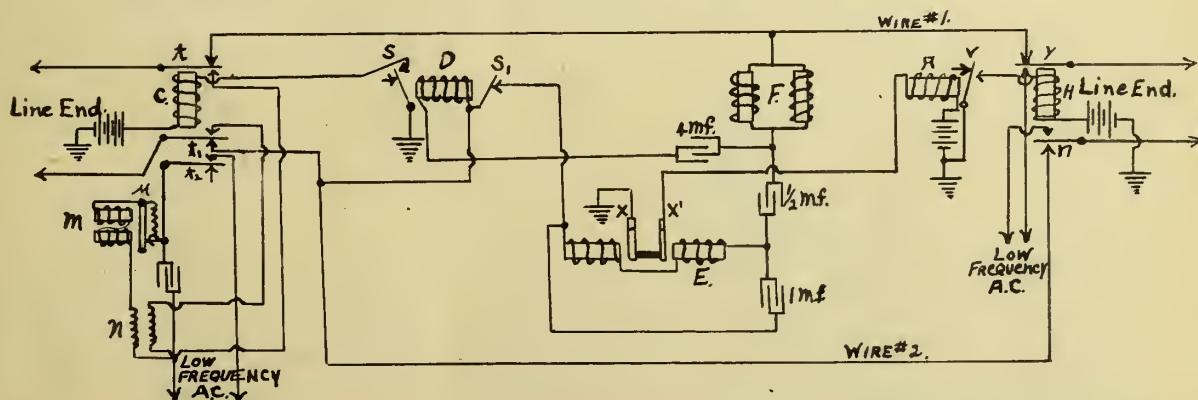
Station "B". At each station the coils, condensers, jack, drop, telegraph^{in present} and batteries are connected as shown by the schematic drawing. The pair of line wires are used as the telephone circuit, while each line wire with a ground return constitutes two separate telegraph circuits. The telephone currents cannot enter the telegraph circuits, as they are impeded by the impedance coils "m, m₁, m₂, m₃". The reason for this is seen from the equation for reactance which is $2\pi fL$, where f is the frequency of the transmitting e.m.f. and L is the inductance of the coil. The highest frequency that ordinarily occurs in conversation is about 750 periods per second, 300 periods per second being an average frequency. It is then seen from the expression given above for reactance that the latter is large for voice currents, and the telephone current is choked back from the telegraph circuits. On the other hand, under the ordinary telegraph operating, the impulse currents on closing the keys are not frequent enough to cause any measurable impedance to these currents. In addition, the two coils of wire on each impedance coil are so connected that they magnetize the core in opposite directions, thus acting as two impedance coils in series to the telegraph or telephone currents. This method of winding makes less impedance to the telegraph currents and a proper amount for the voice currents.

The telegraph currents are prevented from entering the telephone circuits by the condensers marked e, e_1, e_2 and e_3 . If any real sharp instantaneous telegraph current should pass through condensers f, f_1, f_2 or f_3 they will pass through half the windings of coils n or n_1 to ground, with little inductive opposi-

tion. "B" and "B₁" are in series through the ground and act as one single line battery for the corresponding instruments at stations "A" and "B". Likewise for B₂ and B₃. Condensers C₁, C₂, and C₃ serve to keep the high frequency currents, which might happen to get through any of the impedance coils, from completing a circuit through the telegraph instruments and battery to ground.

The question may come up as to how one telephone station calls the other. This is done with high frequency alternating current. The ordinary low frequency alternating current used at Bell Exchanges for local ringing, or on metallic long distance lines, cannot be used in Simplex or Composite Systems, since the impedance of coils m , m_1 , m_2 , m_3 is not great enough to keep the ringing current from passing through the telegraph instruments. The impedance of these coils is greater to high frequency current, and hence passes through the telephone circuit only. The high frequency current as sent out from one station is not impressed directly on the telephone drop at the other station, but is passed through a specially made relay which automatically connects the ordinary low frequency current across the drops.

Description of High Frequency Apparatus:--



The ringing apparatus is connected in the jack and drop circuit at each station in the Composite. Considering Station B, the wires between the jack springs and condensers e_2 and e_3 may be imagined cut in two. The drop end of the ringing set goes to the wires leading to the jack springs. The line end connects to the wires leading to condensers e_2 and e_3 . When it is desired to ring from Station B to Station A, the operator bridges low frequency e.m.f. from the plug across the springs of the jack. The current passes, say, over wire #1, through coil F and the 4 m.f. condenser into relay D and returns on wire #2. Relay D is an alternating current relay, and the armatures s and s_1 are pulled toward the relay poles, and held as long as the current is flowing. S throws a ground to the winding of relay C, magnetizing it and pulling armatures t , t_1 and t_2 towards it's poles. t and t_1 connect the line end of the apparatus across the secondary of induction coil N. The windings of this coil are in the ratio of 1 to 1. t_2 closes the low frequency e.m.f. through the primary of N and the so called interrupter M.

M works on the principle of a vibrating door bell. Armature u rapidly makes and breaks the alternating current to the primary of N, and the high frequency induced current in the secondary passes out over the line to Station A. All relays and apparatus being considered normal at Station A, the current coming in on the line end of the apparatus passes through F and the $\frac{1}{2}$ m f condenser into relay E. The high frequency current does not operate relay D. Armature X' is polarized at the end between the poles, and vibrates rapidly. X is simply a thin stiff spring capable of conducting electric current. When normal, this spring connects ground to relay A, which is constantly energized. The high rate of

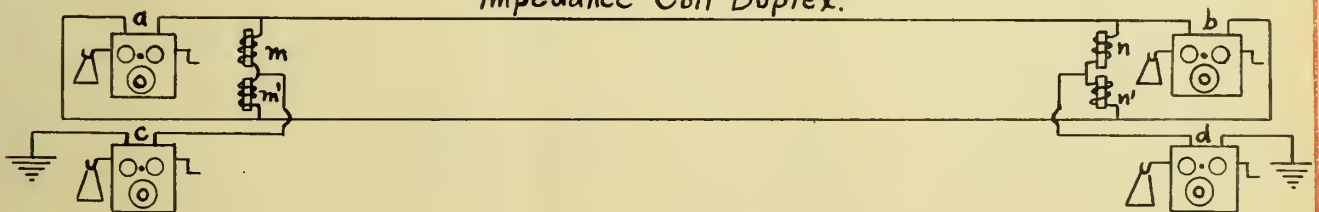
vibration of X' keeps X vibrating, and almost a constantly broken contact is caused between the two. At any rate, the contact at any one instant is not enough to energize A sufficiently to pull the comparatively heavy armature V , which has fallen back due to the cut off of the ground connection. V then throws ground to H which is energized, and armatures Y and Y' bridge the low frequency current across the Composite Drop signal.

The 4 m f and $\frac{1}{2}$ m f condensers in the circuits for relays D and E serve to keep the windings from short circuiting wires #1 and #2, since, upon talking, the voice currents travel over these wires to and from the jacks at the stations.

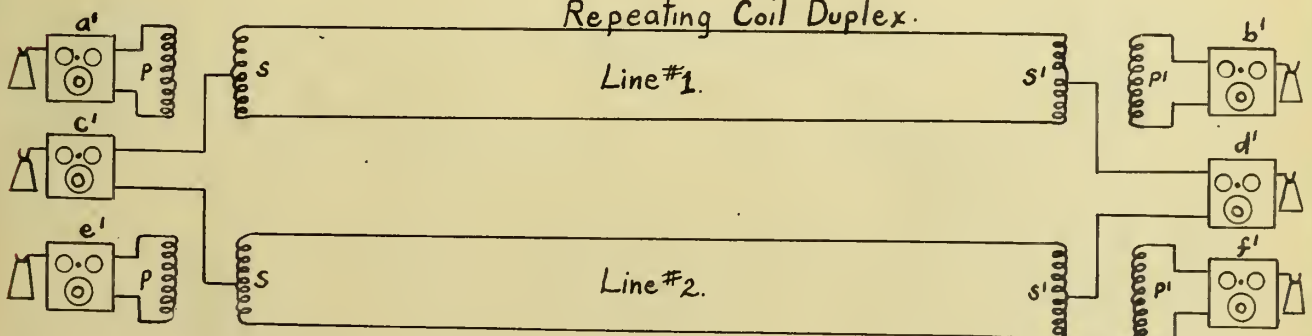
In duplex telephony, the circuits are arranged in about the same manner as for simplex telephone and telegraph systems, telephone instruments being substituted for the telegraph apparatus.

The circuits are shown by following sketches, the switch-board connecting apparatus not being represented in the diagrams.

Impedance Coil Duplex.



Repeating Coil Duplex.



In the impedance coil duplex, telephones a and b are the main line phones. Telephones c and d , impedance coils m, m', n, n' and the line wires constitute what is termed a phantom circuit (ghost circuit), because it is an extra circuit obtained without the addition of any more line wires than are already in use for telephones a and b .

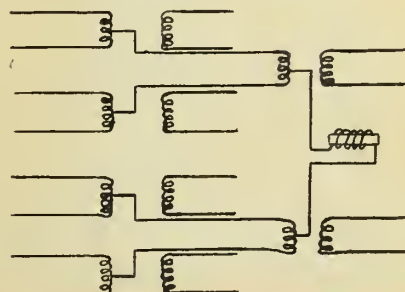
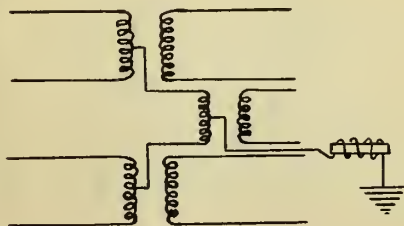
In the repeating coil duplex, telephones a' and b' are the main line phones for one circuit, and phones e' and f' are the same for another circuit. In this system, telephone c' , secondaries s and s' of circuits 1 and 2, respectively, and telephone d constitute the phantom circuit. The external line of circuit 1 is termed the "Physical" for telephones a' and b' . Likewise, the external line construction for circuit 2 is the "Physical" for telephones e' and f' .

Representative Circuits between Cities & Intermediate Towns.

In the accompanying schematic drawings with this Article, the main line telephone terminations, phantom circuits, telegraph simplexes and physicals are shown in their proper combination for simultaneous operation. These circuits can be electrically analyzed in the same manner as was done in the preceding circuits representing the principles of combination.

The method of taking taps off at towns between cities on throughlines are illustrated by these drawings.

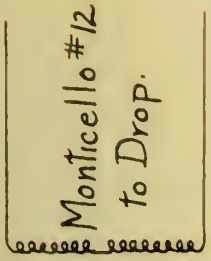
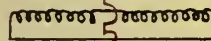
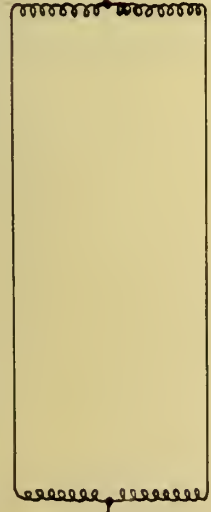
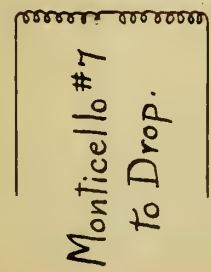
Where one end of a telegraph termination is connected to the center point of the phantom circuit repeating coil, this method of connection is spoken of as "simplexing the phantom". It would seem that this simplexing could be carried on indefinitely, but this is not so, since the transmission for the last simplex is gradually reduced, and it would not only be necessary that there be an increasing transmission voltage for each succeeding simplex, but the line would work "heavy", the equilibrium becoming more and more unstable. The additional expense of high voltage generators would also soon offset the gain in decreased line construction between cities. The largest number of circuits well within range of successful operation would be about four individual circuits simultaneously operating over two physicals and the ground between two stations, or seven operating over four physicals. Diagrams illustrating the meaning of the above statement are shown below.



City of Decatur.

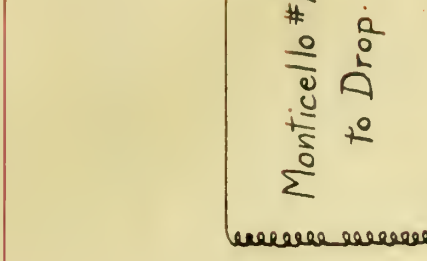
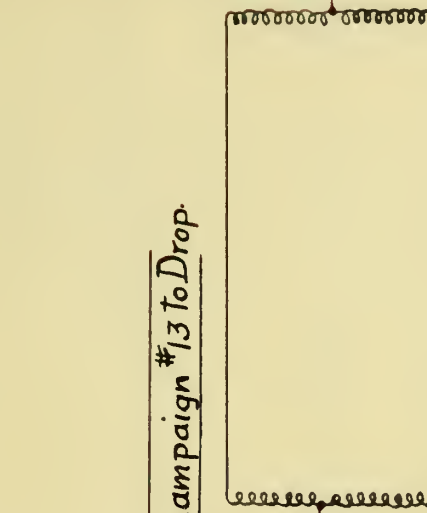
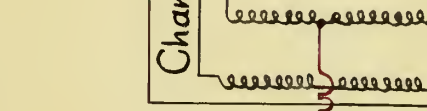
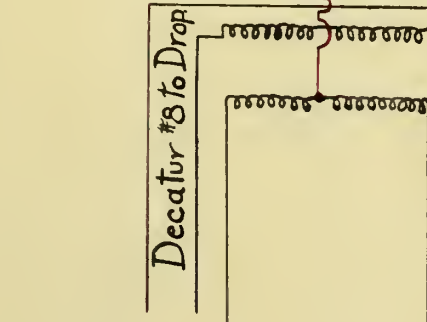
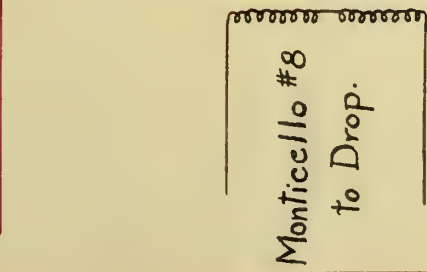
City of Monticello.

City of Champaign.

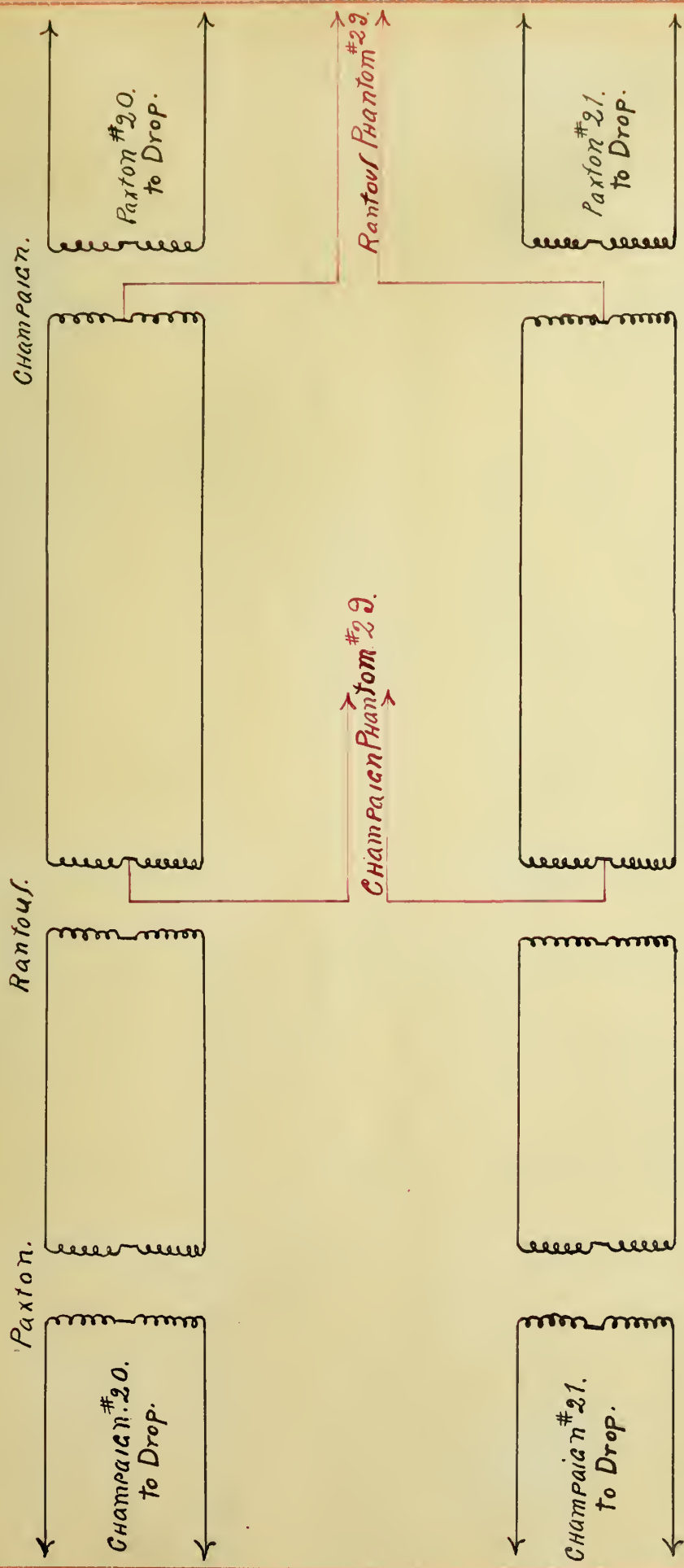


Champaign Phantom #10 to Drop.

Decatur Phantom #10 to Drop.



I.



City of Champaign.

Danville #72 to Drop.

Danville #81 to Drop.

Danville #82 Phantom To Drop.

Monticello #12 to Drop.

New White Heath Phantom To Drop.

New Monticello Line to Drop.

City of Danville.

Champaign #72 to Drop.

Champaign #81 to Drop.

Champaign #82 To Drop.

Monticello #70 To Drop.

TEL. INST.

Onto Springfield.

TEL. SIMPLEXING Apparatus Phantom.

City of Monticello.

City of White Heath

City of Decatur.

Decatur #10 to Drop.

Champaign #12 to Drop.

New Champaign Phantom To Drop.

New Champaign Line to Drop.

Considerations necessary in External Line Construction.

When electric circuits are in close proximity, they induce currents in each other. This inducing action of one circuit on another is spoken of as mutual induction. The fact that an e.m.f. is induced in one circuit by another is explained by the same reason that an e.m.f. is induced in the secondary of a transformer, when a pulsating or alternating current is impressed on the primary of the same transformer.

This mutual induction is very detrimental to telephone lines, since a receiver is a very sensitive apparatus and will give an audible sound by a very small fraction of a milli-ampere.

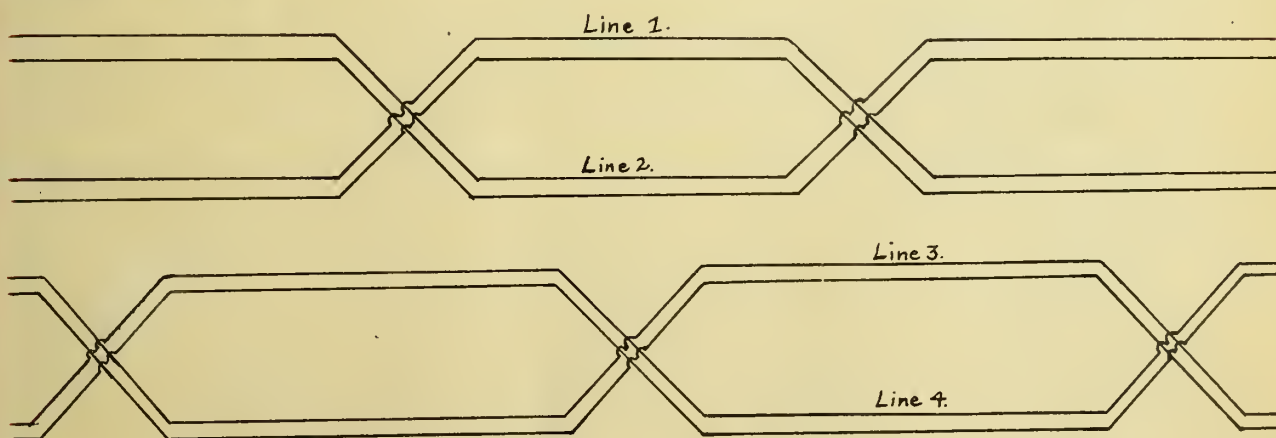
The foreign noises heard in the receiver may be due to one or more of several causes. The sudden shifting of the earth's magnetic field may induce currents in the line; earth currents, due to difference in potential between the ground plates at the ends of the lines, may also pass through the telephone instruments producing the same results; there may be leakage from other lines; or mutual inductance between a line and neighboring lines; electrostatic induction between lines, this being the principal cause for cross talk heard at the instruments.

The latter mentioned cause for noise in the receiver, namely electrostatic induction, is due to a sort of condenser action between a telephone wire and a neighboring wire, small discharges taking place between one wire and the other.

The causes mentioned above for these unwelcome noises are more serious in multiplex telephony than in ordinary lines containing an instrument at each end of the line, since a very small stray current induced in one of the physical wires will cause an

unbalancing effect, and sounds will not only be heard in the particular main line instrument, but also in the phantom instrument.

Where there are a number of wires of various circuits running parallel in the same lead, the electromagnetic and electrostatic interactions may be balanced up entirely by "transposition" of the lines, which consists in reversing the mutual position of wires with respect to each other at certain intervals. To make this transposition, all that is necessary is to take up slack enough in the conductors to enable them to be shifted a certain number of pins to the right or left as the case may be. This is generally done at the point of transposition by means of a double groove insulator. One scheme of transpositions, used on Physicals containing phantoms, is shown below.



If the section of line is sufficient to make the number of transpositions to come out an even number, 1300 ft. has been proposed as the best interval between the transpositions. Otherwise, the 1300 ft. intervals must be lengthened out or shortened, as the case may be, to make the total number come out even between terminating points. If there are more than four circuits

on the same cross arm, they are all transposed with respect to one another in the same manner. On the next cross arm above or below, the method is the same, except that the two circuits in the same perpendicular plane are transposed at half distances on each side of the transposition point for the circuits on the reference cross arm.

This method is called phantom transposition and is done on phantom transposition brackets consisting of a vertical hanger supporting two double groove insulators at a distance of about two feet from each other.

If any ordinary telephone lines with a telephone at each terminating point should run along in the same lead with the physical lines, they are transposed by the regular standard method for such lines.

Great care must be taken to use wires of uniform conductivity and size, insulators of same resistance to ground, and accurate symmetrical spacing of conductors upon the poles. The resistance of the conductors is relatively of less importance than careful attention to symmetry. Indeed, where the resistance of conductors is exceedingly low, more care in regard to exact symmetry is necessary. To get the best results, an entire pole line should be constructed as a unit, and additions should not be made to this line, unless the additions were an integral part of the original scheme of circuits. While it might not be impossible to transpose, successfully, circuits having different characteristics, the scheme is sufficiently intricate under the most uniform conditions, and hence any irregularities should be avoided.

A single physical circuit has an easily measured resistance, and distributed capacity and inductance, which may be determined.

A phantom circuit, using these two conductors in parallel for each side of its circuit, will have but half the resistance of a single physical circuit. The change in inductance and capacity as compared with a physical will depend somewhat upon the relation between the component physicals, as to whether they are on same or on adjacent cross arms, but will necessarily have an increased capacity and a reduced inductance, altering the transmission constants. Indeed, the attenuation of the phantom circuit will generally be less than that of one of its component physicals, and therefore the results somewhat better.

It is to be remembered that resistance alone will diminish the current equally for all the component harmonics representing the human voice; while inductance and capacity affect currents of different frequencies unequally. Inductance retards the higher harmonics more than the fundamental tones of the voice, reducing the finer points of articulation, and making voice recognition more difficult. Capacity would seem to have reverse effect, since the capacity of a line offers a return circuit that falls short of the entire line, and in giving a better path for the higher harmonics in this shorter circuit, also diminishes the effectiveness of the higher harmonics at the receiving end, and therefore both inductance and capacity offer similar disturbing influence upon the characteristics of the voice. It is well known that deep voices carry better over long lines than those that are high-pitched, and that men can talk better than women over long lines for these reasons. It has been found that extra inductance inserted in the lines will operate with the existing line capacity to effect a better transmission of the higher harmonics. Thus, a very satis-

factory contribution to telephony has been the Pupin load coil.

Pupin coils are simple inductance coils inserted in series in both conductors of the line at symmetrical points and at ~~fre~~ frequent intervals, and they serve to restore to the conductors and carry to the end of the circuit, where wanted, a greater proportion of the higher harmonics, improving the articulation as well as the volume of sound.

The Bell Telephone Company has repairmen in readiness at any time to send out on their lines. A large enough force of repairmen are employed on each Exchange, such that the largest probable number of lines that would get in trouble at a time may receive immediate attention. One half the line between two city Exchanges is usually taken care of by the men at each city.

The amount of revenue lost to the Company for a given time that a line may be out of order varies with the importance of the line. In case one of the external lines of a duplex or multiplex system gets in trouble, two telephone circuits are out of use, and the Company loses twice as much as for one circuit during a given time interval.

If a line should become crossed, grounded or open at any time in the night, a repairman is dispatched without delay to the nearest station, and immediately at day-break he is expected to proceed to clear the line. In many cases the men must repair the line by moonlight or if this is not possible they will make tests on the same until the trouble is located within a short section of line, whence it will be cleared at day-break. The lines are busier during the day, and arrangements are especially made to have lines in good order to give satisfactory day service, even if this is not possible at night.

Principles of Duplex and Quadruplex Telegraphy, and Combination with Multiplex Telephony.

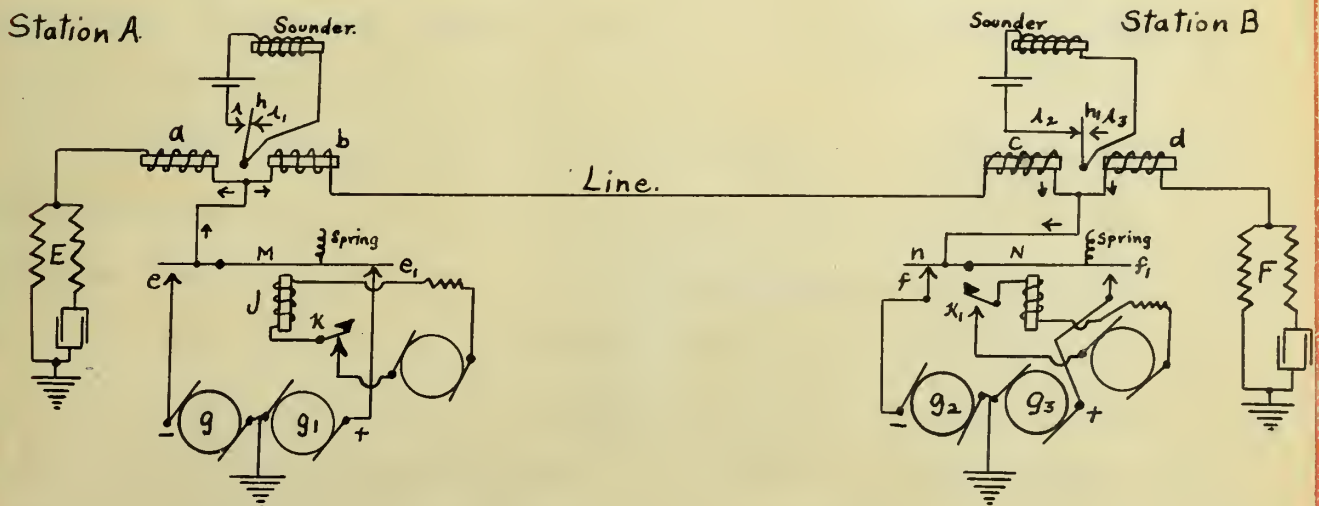
Duplex Telegraphy is the simultaneous transmission of two telegraphic messages over the same wire, one being sent in each direction.

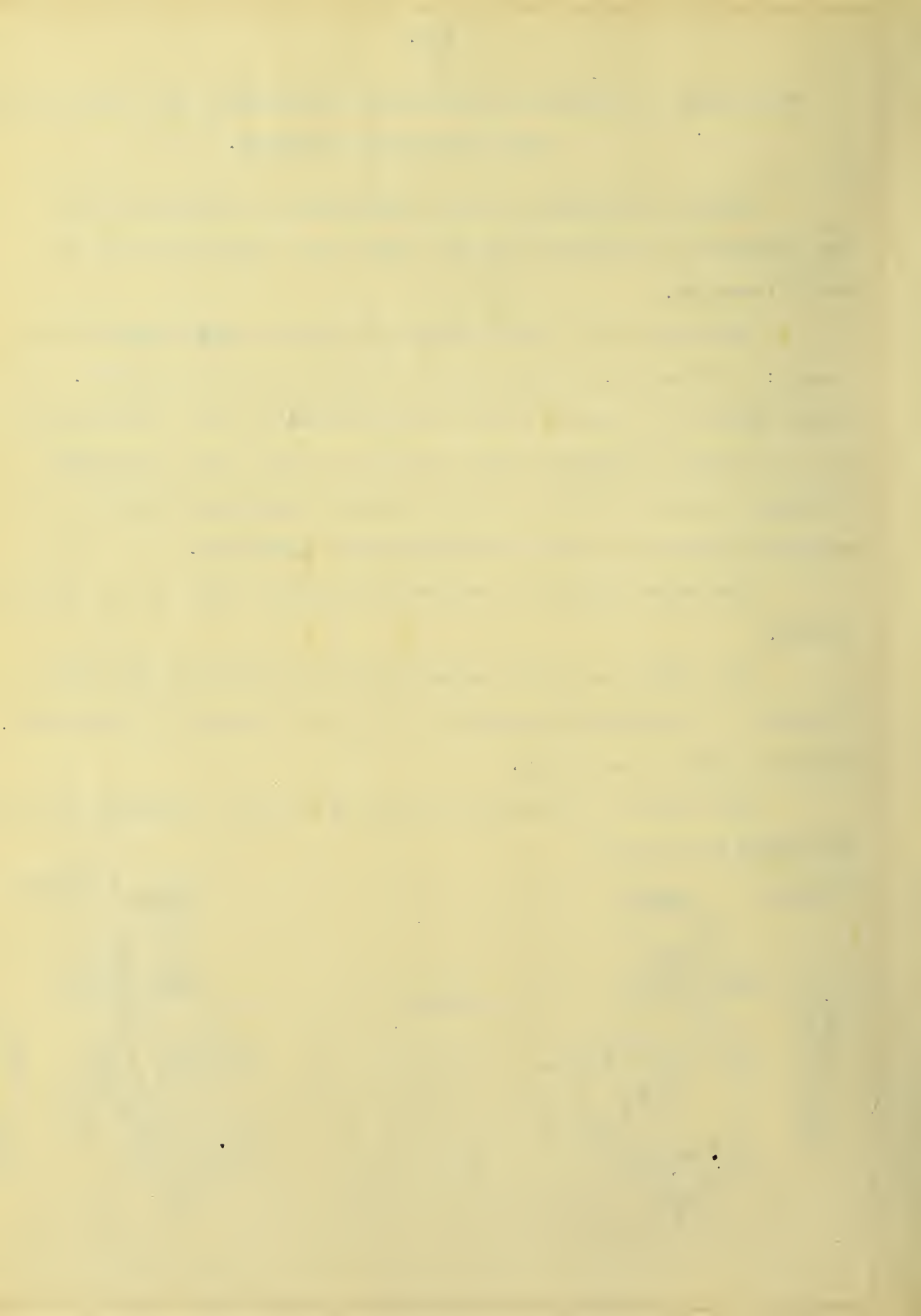
There are about three types of systems used commercially, namely: differential duplex, polar duplex and bridge duplex. The polar duplex will be the only form described in this article, since it is desired only to show how this may be used with multiplex telephony equally as well as the ordinary telegraph relays, depending wholly on series connection for operation.

The polar duplex is used more than any other in the United States.

The relay is of the polarized form, depending upon the direction of currents through the coil as to movement of armature from one stop to the other.

The theory of operation, with the aid of a diagram, will be presented as follows,





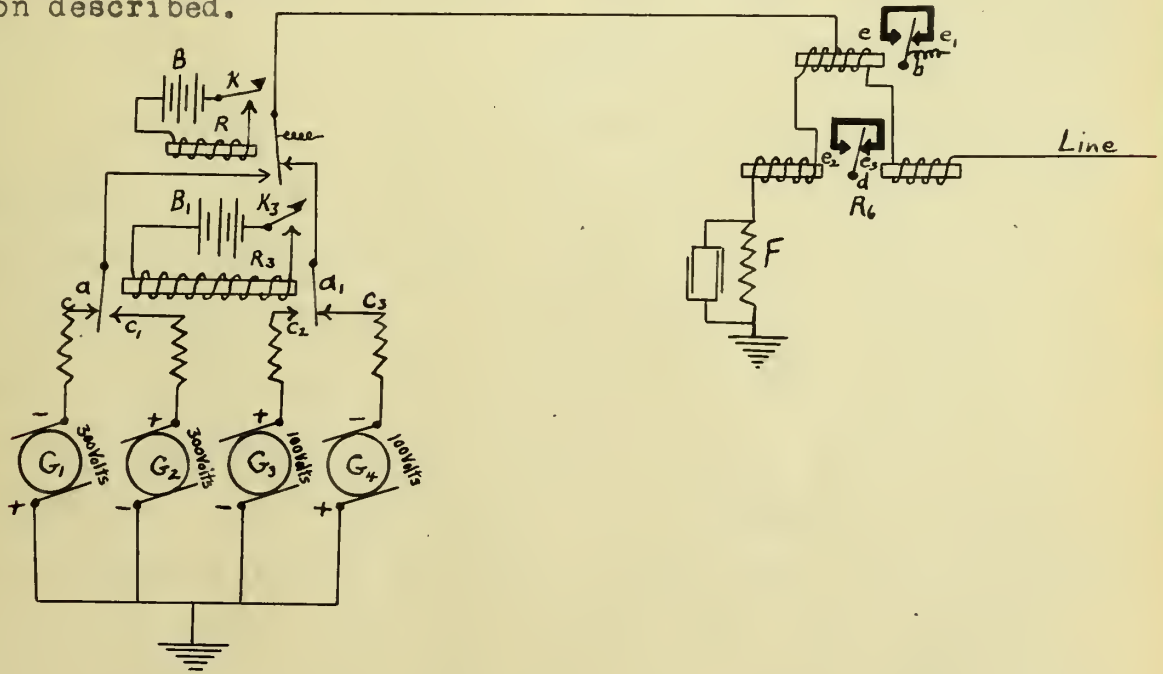
E and F of the equipments at Stations A and B respectively are called the artificial lines. Each contains resistance and capacity equal to that of the line wire between the instruments. The armature of each relay contains a permanent north magnetic pole on one side and a south pole on the other. When keys K and K₁ are open, armatures M and N make contact on c and f respectively. Coil d is then energized by g at Station A, the circuit being ~~complete~~ completed through the ground and artificial line E. Likewise, coil d is energized by g₂ at Station B. Armature h rests against back stop i₁, and h rests against i₂. The sounders are thus open. If K is closed at Station A, armature m is pulled against contact e, by magnet J. A current then flows from g, through line coil b and the line wire to coil C and completes the circuit to g, through n, f, g₂ and the ground. g, and g₂ are now in series, and h is pulled against i₁, magnets a and b both attracting h. Double strength current is however flowing through b and this is why h is pulled against i₁. This same current flows in C and h, is pulled into contact with i₂, and the sounder at Station B is closed. When K is released, c is without current and d pulls h, against stop i₂, opening the sounder circuit. The current is reversed in d since g now furnishes the excitation.

Thus, messages are sent from Station A to Station B, the instrument at the latter place receiving the impulses while h remains against back stop i₁. Likewise, messages can be sent from Station B to Station A, h, remaining against back stop i₂. When both keys K & K₁ are closed, the positive poles of equal dynamos will be connected at each end of the line circuit; consequently there will be no current in the line circuit. However, current will flow

in each artificial coil a and c. The current flows in the proper direction to reverse the normal polarity of the relays, and each armature will close its sounder circuit. Thus, station B can be sending a message to Station A and A can be sending one to B, all at the same time over the single line wire and ground. There is generally a sending and receiving operator at each office. It is evident that there is a saving with this system of one line circuit between stations.

Quadruplex telegraphy is a simultaneous transmission of four independent messages over one wire, two being sent in each direction.

The apparatus is the same at each end of the line, but for simplicity, that at one end will be shown, and the theory of operation described.



R is called a transmitting relay.

R_3 is the pole changing relay for contacts c , c_1 , c_2 , and

c_1 , each of the latter being connected through some suitable resistance to a pole of one generator, as shown.

R_1 is a neutral relay.

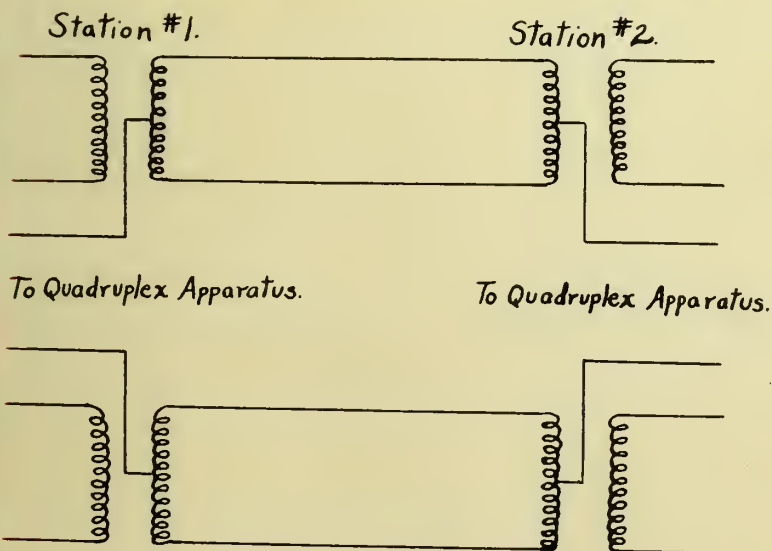
R_2 is an ordinary polarized relay, as used in duplex telegraphy.

R_1 and R_2 are the relays from which messages are taken.

Suppose the line is not being used, whence K and K_1 are open. G_1 is then the only generator in the circuit, the positive pole being grounded, and the negative being connected through to the middle of the winding of R_1 . If it is desired that a message be sent by the operators at K , the negative terminal of 300 volts is connected to the line through c and a . If K_1 is closed at the same time, the positive of G_1 (300 volts) is connected to the line, the negative being grounded. If K is open and K_1 is closed, the positive of G_1 (100 volts) is connected with the line, and the negative is grounded. A similar operation may be occurring at the instrument on the other end of the line. F is the artificial line and contains resistance and capacity equal to that of the line wire connecting the stations. Whatever generator is connected at the station considered, the current will then divide equally through both windings of each relay, and neither R_1 or R_2 will attract their armatures. The winding of R_1 is so designed that this relay will not operate on either 100 volts or 200 volts, but will operate on 300 volts or more. Hence the closing of K_1 will not affect the neutral relay R_1 at the other station. But the closing of K causes the 300 volts, whether the positive or negative be connected to the line wire, to operate R_1 at the other station. R_2 at the other station does not operate due to the 300 volts or more which

may be in the circuit, since the current will travel both windings of the relay in such a direction as to prevent the resultant magnetism from being strong enough to attract the polarized armature from one stop or the other. By a further study of the circuit, it will be seen that for any possible connection in the circuit of the dynamos at both stations, through the operation of K and K_3 , relay R_5 at one station will only respond to K at the other, and likewise R_6 to K_3 at the other station. Two receiving and two sending operators are employed at each station.

From the fact that duplex and quadruplex operation between stations requires simply two conductors between the places, namely, one line wire and the ground, or two line wires, it is quite evident that the operation could be carried on over two physicals of a multiplex telephone system. If it is desired that a message



be transmitted on to Station #3 through Station #2, it would be necessary that this be done with some form of repeater. Due to the difficulty in keeping repeaters in correct working order for all conditions of weather and irregular conditions of the

physicals between average telephone exchanges, repeating messages is resorted to only on a small scale.

In case a telegraph circuit is to be operated through several cities over the telephone lines, it is generally done with the ordinary

magnetic telegraph relays. The telephone circuits can however be extended through any number of cities in the multiplex system.

If a large amount of telegraphing is to be done between two cities, and loss of time in operation counts for much, duplexes or quadruplexes are principally operated on the physicals of the telephone systems. It is requisite that the lines be absolutely clear of ground, and that capacity and inductance be small, in order that either of the telegraph circuits and the telephones shall work satisfactorily in the combination. This is especially true if the ground is used as one conductor for the telegraph system.

Discussion on Economy of Systems.

Purely multiplex telephone or multiplex telegraph transmission, including their combination, are economical from many standpoints.

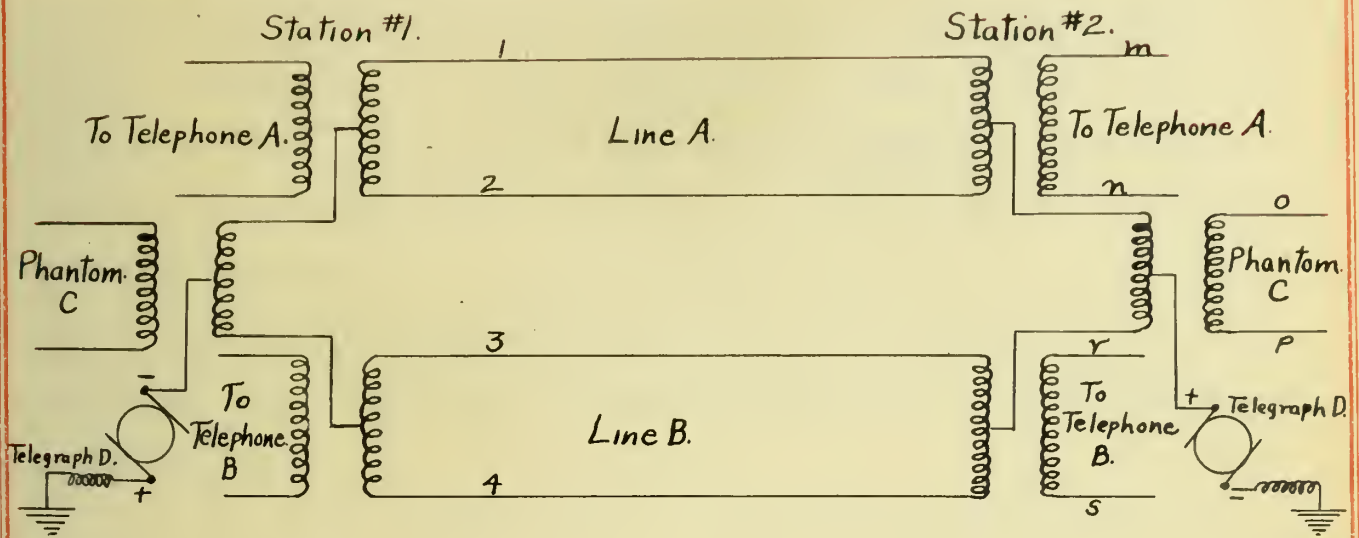
The saving in line wire, poles, cross-arms, insulators, on labor cost of line construction, maintenance, interest on capital invested, and depreciation are the principal items to be considered, and are to be balanced against the increased cost of terminal equipment before a permanent installation of any of these systems be decided upon between cities. It is obvious that the longer the line, the greater is the gain.

Were the capacity and inductance of the phantom circuit, composed of the four wires of the main lines, the same as that of a single line, the gain in effective transmission would be greater than that of a main line between two given stations. This would be true, since assuming the main line wires as composed of a given material and size, there are two wires for each side of the line of the phantom circuit. As a matter of fact, the actual efficiency is not increased 100% but may be between 60% to 90%. If duplex or quadruplex telegraph operation is to be carried on simultaneously over the telephone lines, it is evident that a much longer line than for simple telegraph or phantom telephone operation would be required for a given economy, since multiplex telegraph equipment is elaborate and very expensive.

A few conditions of breakdown of the parts of a multiplex system, and effect on economy will be considered.

There are five main cases of trouble that may occur in electric circuits; namely, short circuit, open circuit, cross between

lines, grounded line^{wire} and induction due to other circuits in the vicinity.



Suppose line A should become short circuited, due to some cause or other. This line would be the only one out of use between Stations #1 and #2. Hence, assuming that the three telephones and one telegraph may be worked between the stations when all lines are clear and that the income is the same from each line for a certain time period of operation, the Company loses 25% of the normal return. If line B becomes short circuited at the same time, the company loses 50%.

In case wire #1 or #2 of line A becomes open, this line and phantom C would ~~out~~ be out, and the Company would lose 50%. If wires #3 or #4 should be opened, it would not be possible to use telephones A and B, but phantom C and telegraph D could be worked. There is a 50% loss.

A cross between lines A and B would put telephones A and B and phantom C out of order, but telegraph D would work. Thus a 75% loss results.

If line A becomes grounded, telephone A and phantom C would

be too noisy to use, and telegraph D would be inoperative. However, the tendency to ground noise on line B would be zero, since the phantom connection is at the center of the secondary winding of the repeating coil. This line would be operative, and the loss is 75%. Should lines A and B both become grounded, the loss is 100%. Induction on A or B would cause a 50% loss, since the phantom would be affected.

The above discussion was for the external lines only. Consider the same conditions for the primary sides of the respective repeating coils.

If a short circuit should occur between wires m and n, telephone A would be out, and the loss 25%. There is the same percent of loss for shorts between wires o and p or r and s. An open circuit in any one of these wires would result in a 25% loss.

Should wires m and n become crossed with either r or s, no conversations could be carried on over telephones A or B, but phantom C and telegraph D would remain operative. If wires o or p would cross with m, n, r or s, only the phantom and one of the other telephones would be impaired. There is a 50% loss to the Company for any of the above mentioned crosses.

If a ground connection was made with m, n, r or s, only one of the circuits would be disabled due to the ground noise which would result in the particular telephone circuit receivers. The loss is then only 25%, the latter varying directly with the number of these telephone units which are so grounded. Should any of these five cases occur in the primaries at Station #1, the effect on economy would be manifestly the same.

When the central office coils and apparatus for multiplex systems has once been carefully installed, there is practically very

little trouble liable to occur at the terminations. The external lines are subjected to all trouble which might befall any wires strung on poles, but, as stated in the previous article, the Telephone Company has competent inspectors always in readiness to patrol and repair their lines at a moment's notice, thereby striving to serve the people unceasingly with highly efficient telephone and telegraph communication.

#31.

VIII
Conclusion.

In the last analysis, efficient engineering in all public service industry has resulted in the greatest gain to the entrepreneur and other wealth producing humanity. Both of the latter have benefited by new inventions and methods of operation of all types of machinery. It has only been through the gradual and effective process of evolution, by intense work and large sacrifice, that the present state of development in mechanisms has been brought into material evidence. The telephone and telegraph have kept pace with the scientific progress of all utilities, and will probably continue to further develop and assert themselves as indispensable vehicles for transmitting thought from Man to Man.

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